USING SOIL MOISTURE TO DETERMINE WHEN TO SUBSOIL

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ABSTRACT

Determining the optimum time to subsoil depends upon several factors, including maximizing belowground soil disruption, minimizing aboveground soil disruption, and minimizing tillage energy requirements. An experiment was conducted to examine how soil moisture affects these factors and to determine the optimum moisture content to subsoil based on tillage forces and soil disruption. Two different shanks, a straight shank and a "minimum tillage" shank, were tested in a Coastal Plain soil in the soil bins of the National Soil Dynamics Laboratory in Auburn, AL. A three-dimensional dynamometer was used to measure tillage forces and a laser profilometer was used to measure soil disruption. Tillage forces and soil disruption from the soil with the lowest moisture content were found to be greater than results from all other moisture contents tested. The "minimum tillage" shank was found to require more energy and disrupt the soil a lesser amount than the straight shank.

KEYWORDS

Tillage, subsoil, soil compaction, disruption, soil moisture

INTRODUCTION

Compaction of agricultural soils can have devastating effects on crop growth and overall productivity. This has been particularly true in the southeastern USA, where soils have been proven to be highly compactable by natural forces and by vehicle traffic (Cooper *et al.*, 1969; McConnell *et al.*, 1989). Two techniques have been used to minimize the effect of soil compaction. The first method that has proven effective is prevention. Controlled traffic (Dumas et al., 1973), reduced tire inflation pressure (Raper *et al.*, 1995a; Raper *et al.*, 1995b), reduced vehicle size (Cooper et al., 1969), and use of cover crops (Reeves *et al.*, 1992) have reduced the negative effects of soil compaction.

Another technique that is commonly used to alleviate the effects of soil compaction is subsoiling(Campbell *et al.*, 1974; Reid, 1978; Garner *et al.*, 1987). This tillage practice disrupts compacted soil profiles to depths of 12 – 20 in. (0.3–0.5 m). However, it is not a permanent solution because of the aforementioned natural reconsolidation and vehicle traffic. It is common practice in this region to subsoil on an annual basis (Busscher *et al.*, 1986; Tupper *et al.*, 1989). Some research has indicated that subsoiling could be performed less frequently but this entails a greater risk of soil compaction (Colwick *et al.*, 1981; Smith, 1985; Reeder *et al.*, 1993).

Because of the significant draft forces that are required to subsoil compacted profiles, many different types of subsoilers have been designed and tested (Nichols and Reaves, 1958; Choa and Chancellor, 1973; Tupper, 1974; Upadhyaya *et al.*, 1984; Smith and Williford, 1988; Sakai *et al.*, 1993; Reeder *et al.*, 1993; Mielke *et al.*, 1994). However, subsoilers have also been designed to minimize soil inversion which maximizes residue cover after subsoiling (Pidgeon, 1982; Pidgeon, 1983). Many manufacturers now promote the ability of their subsoiler shank to disrupt compacted profiles as well as maintain sufficient residue coverage.

The scheduling of a subsoiling operation is usually ruled by the availability of the producer's time. Many subsoiling operations are performed in the fall of the year when time is usually more plentiful, but some soils reconsolidate so quickly that subsoiling must be performed in the spring for the full benefit to be realized by the summer crop (Touchton *et al.*, 1986; Vaughan *et al.*, 1992). Another consideration for reducing energy consumption of subsoilers has been to target tillage times when soil moisture reduces sliding friction between soil and metal. However, some soils adhere to metals when soil moisture is increased, thereby increasing draft force (Nichols, 1925; Nichols, 1931; Chancellor, 1994).

Another consideration concerning the timing of subsoiling that has not been extensively studied is how to maximize soil disruption, perhaps increasing the long-term

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benefits of the subsoiling event. Subsoiling is routinely recommended when the soil is driest to maximize disruption, but few data exist to support this recommendation (Schuler *et al.*, 2000). Therefore, the objectives of this study are to:

1. Determine the force required to subsoil a Coastal Plain soil at several levels of soil moisture,
2. Determine soil disruption caused by subsoiling at each moisture level,
3. Evaluate the differences in draft and disruption caused by a straight subsoiler and a subsoiler designed for "minimum tillage".

MATERIALS AND METHODS

An experiment was conducted in the soil bins at the USDA-ARS National Soil Dynamics Laboratory in Auburn, AL to determine the force necessary to disrupt a hardpan profile in a bin of Norfolk sandy loam soil (fine-loamy, kaolinitic, thermic Typic Kandiudults) and to determine the amount of soil disruption caused by the subsoiling event. Norfolk soil is a Coastal Plain soil commonly found in the southeastern USA and along the Atlantic Coast, and was selected because it is indigenous in many locations where subsoiling is commonly used to disrupt compacted soil layers. The bin is located indoors, which facilitates the maintenance of constant moisture content for an extended period of time.

A hardpan condition was formed in the soil bins to simulate a condition commonly found in the southeastern USA. This naturally occurring and sometimes traffic-induced hardpan was found approximately 4-8 in. (0.1-0.3 m) below the soil surface and was quite impervious to root growth, particularly at low moisture levels. The hardpan condition was created in a soil bin using a moldboard plow to laterally move the soil and then using a rigid wheel to pack the soil left exposed in the plow furrow. A small amount of soil was packed at a time and the entire procedure repeated until the entire bin had been traversed. The surface soil was then bladed and leveled. Variations can occur between bin fittings, but within one bin fitting, the same depth of the hardpan can usually be achieved with little error.

The shanks used for the experiment were manufactured by Deere & Co. (Ankeny, IA; Fig. 1). The straight shank is 1.25 in. (31.8 mm) thick with a 5 in. (127 mm) LASERRIP™ Ripper Point and is currently used on the John Deere 955 Row Crop Ripper. The minimum tillage shank is 0.75 in. (19 mm) thick with a 7 in. (178 mm) Min-till point and is used on the John Deere 2100 Minimum till Ripper.

These shanks were mounted on the dynamometer car to a 3-dimensional dynamometer, which has an overall draft load capacity of 10,000 lbs (44 kN). Draft, vertical force, side force, speed, and depth of operation were recorded continuously for each shank test. The speed of tillage for all tests was held constant at 1 mi hr^{-1} (0.45 m s^{-1}). The depth of operation of 13 in (33 cm) was kept constant for all tests.

The soil bin was treated as a randomized complete block design with four moisture contents, two shank types, and four replications. Four subsoiling runs were conducted side-by-side across the width of the bin with eight separate lanes being constructed along the length of the bin. This arrangement allowed all 32 runs to be conducted accurately. The approximate size of each plot was therefore 4.9 ft (1.5 m) wide by 16.4 ft (5 m) long. The spacing across the bin was sufficient to ensure that disturbed soil resulting from a previous tillage operation would not affect a current test. Each set of force values obtained from each plot was averaged to create one specific value per plot of draft, vertical force, and side force. Preplanned single degree of freedom contrasts and Fisher's protected least significant difference (LSD) were used for mean comparison. A probability level of 0.10 was assumed to test the null hypothesis that no differences in tillage forces or soil disruption existed between the soil moisture levels or between shanks.

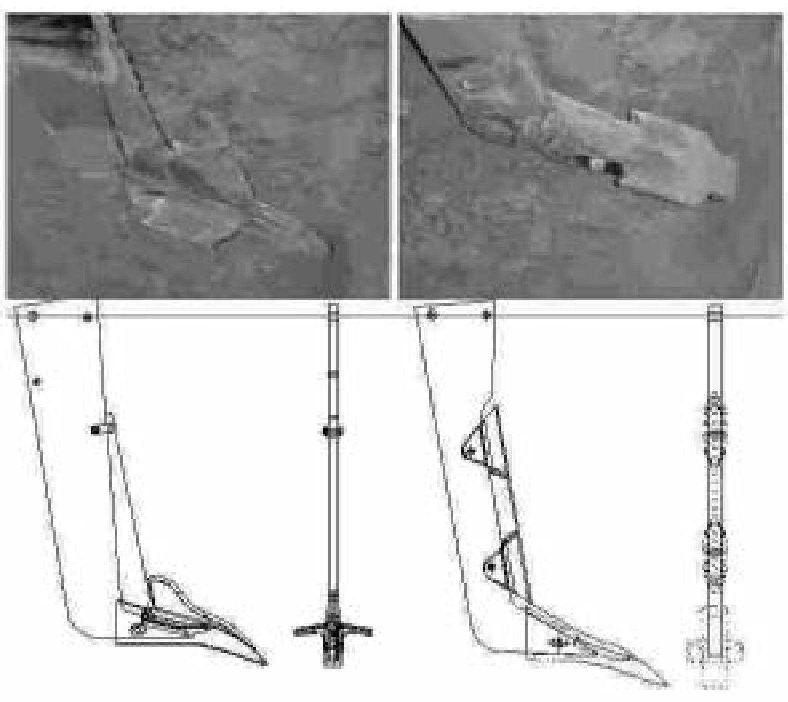

Fig. 1. "Minimum tillage" shank (left) and straight shank (right) used for experiment.

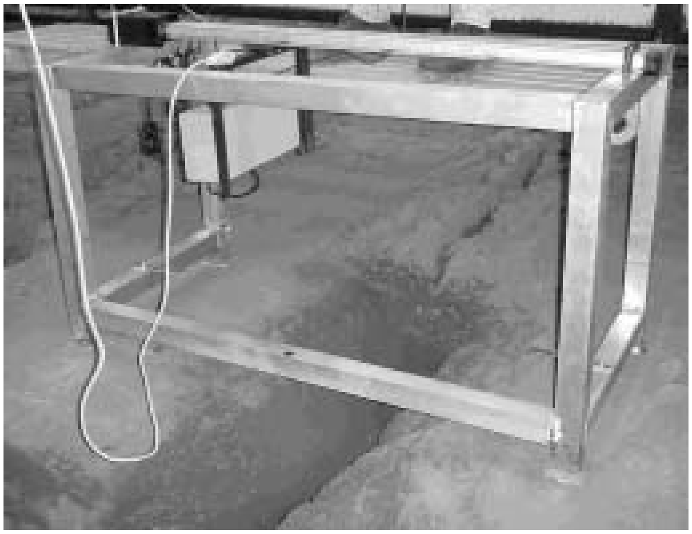

Fig. 2. Laser profilometer used to measure area of spoil and trench.

The soil bin was initially wet to a completely saturated soil condition prior to the first set of experiments. After this set of tests was conducted, the soil was left uncovered for several days to allow a different soil moisture condition to develop. Daily measurements of soil moisture using a time-domain reflectrometry (TDR) probe were conducted to achieve the targeted soil moisture level so that the next set of tests could be conducted. This procedure was repeated three times to allow four distinct levels of soil moisture to be tested.

Before the shank tests were conducted in each plot, a set of five-cone index measurements was acquired with a multiple-probe recording penetrometer. This set of measurements was taken with all five-cone index measurements being equally spaced at a 7.5 in. (20 cm) distance across the soil with the middle measurement being directly in the path of the shank. As soon as the shank had been tested in each plot, another set of five cone index measurements was also taken in the disturbed soil, close to the original cone index measurements.

Measurements of soil moisture were taken in undisturbed regions of each plot for analysis. Values of gravimetric moisture content were measured at depths of 0-6 in. (0-15 cm) immediately after the experiment was completed. Bulk density values were taken at depths of 2-4 in. (5-10 cm), 8-10 in. (20-25 cm), and 12-14 in. (30-35 cm) in each replication at the end of test.

After each set of tillage experiments was conducted, a laser profilometer (Fig. 2) was used to determine the width and volume of soil that was disturbed by the tillage event. The disturbed soil was then manually excavated from the trenched zone for approximately 3.3 ft (1 m) along the path of plowing to allow several independent measurements of the area of the subsoiled or trenched zone. Care was taken to ensure that only soil loosened by tillage was removed.

RESULTS AND DISCUSSION

Volumetric moisture contents as determined by TDR were 16.3% for wet soil, 13.3% for moist soil, 8.3% for dry soil, and 5.8% for very dry soil. The gravimetric moisture contents at the 0-6 in. (0-15 cm) depth were 11.2% for wet soil, 9.9% for moist soil, 6.5% for dry soil, and 6.1% for very dry soil.

Bulk density values showed the approximate location of the hard pan installed in the soil bin. Surface bulk density from a depth of 2-4 in. (5-10 cm) was found to be 1.58 Mg m^{-3} while the soil within the hard pan at a depth of 8-10 in. (20-25 cm) had a bulk

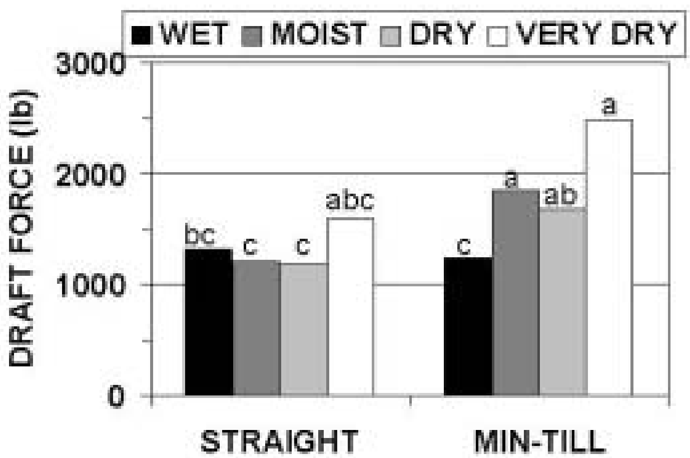

Fig. 3. Draft forces from shanks. Differences in letters indicate statistical differences at $P = 0.10$ across both shanks.

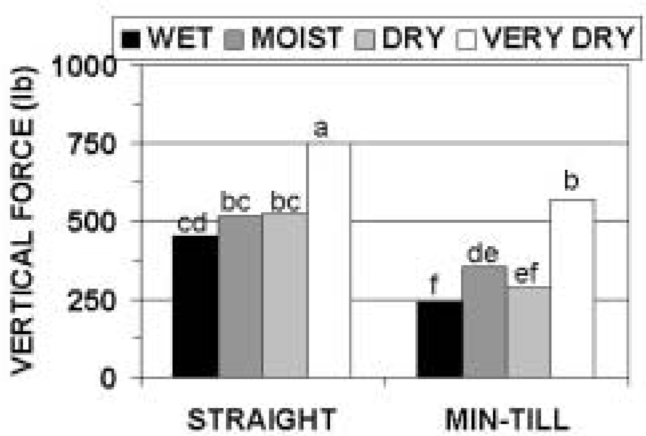

Fig. 4. Vertical forces from shanks. Differences in letters indicate statistical differences at the 0.10 significance level across both shanks.

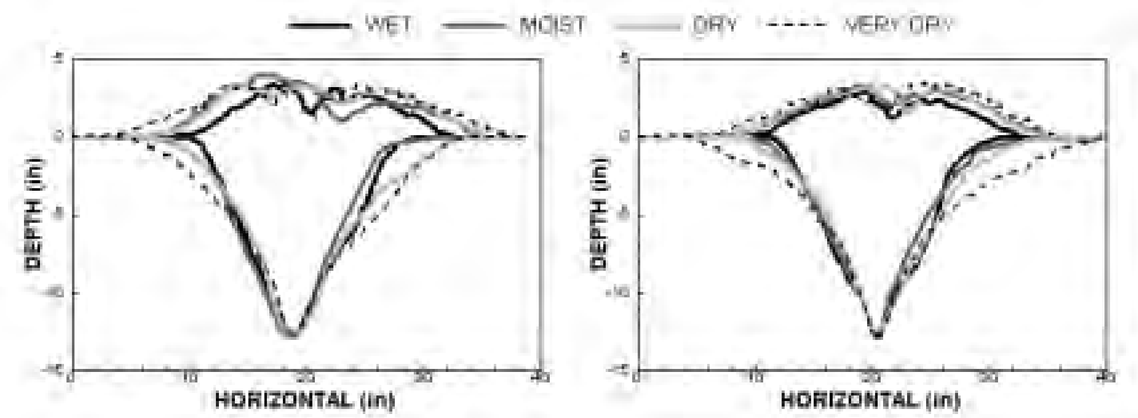

Fig. 5. Spoil and trench areas for straight shank (left) and "minimum tillage" (right) shank, as measured with the laser profilometer.

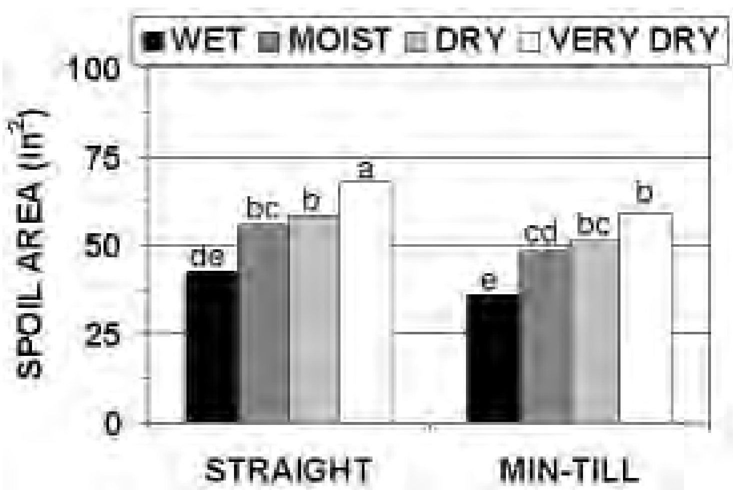

Fig. 6. Spoil area measured with profilometer. Differences in letters indicate statistical differences ($P = 0.10$) across both shanks.

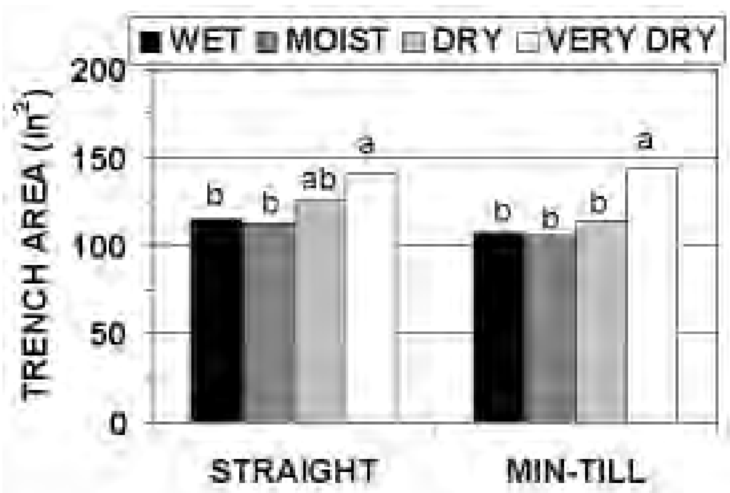

Fig. 7. Trench area measured with profilometer. Differences in letters indicate statistical differences ($P = 0.10$) across both shanks.

density of 1.93 Mg m^{-3} and the soil below the hardpan at a depth of 12-14 in (30-35 cm) had a density of 1.80 Mg m^{-3}.

Soil moisture had a statistically significant effect on draft force averaged across shank type. Draft force from the very dry soil condition was found to differ from all other soil moisture conditions: 1977 lbs (8794 N) vs. 1433 lbs (6374 N) ($P = 0.003$) for the dry soil condition, 1977 lbs (8794 N) vs. 1531 lbs (6810 N) ($P = 0.009$) for the moist soil condition, and 1977 lbs (8794 N) vs. 1283 lbs (5707 N) ($P = 0.004$) for the wet soil condition (Fig. 3). Draft measurements from all other soil conditions were not found to be statistically different from each other.

Draft force measurements were also found to differ based on the type of shank used ($P = 0.001$; Fig. 3). The straight shank was found to require 1330 lbs (5916 N) of draft force averaged over all moisture contents while the "minimum tillage" shank required an average of 1769 lbs (7868 N) of draft force. Only in wet soil did the "minimum tillage" shank have a lesser draft force (1242 lbs (5524 N) vs. 1323 lbs (5885 N)), but this difference was statistically insignificant. In all other soil moisture conditions, the draft force of the "minimum tillage" shank exceeded the draft force of the straight shank.

Soil moisture also had a significant effect on vertical force (Fig. 4). Vertical force from the very dry soil condition was found to differ from all other soil moisture conditions: 674 lbs (3001 N) vs. 406 lbs (1806 N) ($P = 0.0001$) for the dry soil condition, 675 lbs (3001 N) vs. 435 lbs (1935 N) ($P = 0.0001$) for the moist soil condition, and 675 lbs (3001 N) vs. 346 lbs (1543 N) ($P = 0.0001$) for the wet soil condition. The vertical force from the moist soil condition (435 lbs (1935 N)) was also found to be significantly greater than the draft force from the wet soil condition (347 lbs (1543 N)). The straight shank was also found to have greater average vertical force requirements than the "minimum tillage" shank, 562 lbs (2501 N) vs. 348 lbs (1547 N) ($P = 0.001$).

Several measurements of soil disruption were obtained with the laser profilometer. The above-surface area, or spoil area, provides a measurement of the amount of soil displaced above the original soil surface by the tillage process. Another measurement of a shank's effectiveness is the area of soil that is disrupted below the soil surface, or trenched area. Figs. 5 shows the averaged profiles of spoil and trenched areas for the two shanks tested at the various moisture contents. These figures show some enlargement of the trench area near the soil surface for the very dry soil condition as compared with other soil moisture conditions.

Decreased soil moisture was found to contribute greatly to increased soil disruption above ground (Fig. 6). The very dry soil moisture condition was found to have the greatest spoil area with a value of 63.4 in^2 (409 cm^2) as compared to all other treatments. The "minimum tillage" shank (48.6 in^2 (313.7 cm^2)) was also found to have a smaller spoil area than the straight shank (56.0 in^2 (361.2 cm^2); $P = 0.006$).

Decreased soil moisture also produced an enlarged trenched area. This value was found to be much greater for the very dry soil moisture condition (142 in^2 (916 cm^2)) as opposed to all other soil moisture conditions (Fig. 7). No statistical differences were found between the two shanks tested at 0.10 significance level.

CONCLUSIONS

1. Tillage forces obtained from the driest soil were found to be significantly greater than tillage forces obtained at all other soil moisture levels.
2. Measured values of soil disruption showed the driest soil to have significantly increased spoil and trenched areas compared to all other soil moisture levels.
3. Increased draft forces were measured for the "minimum tillage" shank as opposed to the straight shank. However, the "minimum tillage" shank reduced aboveground soil disruption (spoil) as compared to the straight shank.

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